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VERTICAL STRUCTURE OF AEROSOLS AND CLOUDS IN THE ATMOSPHERES OF URANUS AND NEPTUNE: IMPLICATIONS FOR THEIR HEAT BUDGETS

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The presentation by Pollack *et al.* is largely contained in a paper appearing in the special issue of *Icarus* (1986; 65, 442-466). The abstract of that paper is reproduced here.

We have attempted to bound the wavelength averaged phase integrals and bolometric albedos of Uranus and Neptune by fitting a wide range of aerosol model atmospheres to their observed geometric albedo spectra. These models are characterized by an upper haze layer of finite optical depth and a lower cloud layer of infinite optical depth at discrete altitudes. Alternative models differ in the assumed value of the particles' single scattering phase function and the wavelength dependence of the haze optical depth. Phase functions ranging from isotropic to those characteristic of particles in the atmospheres of Titan, Jupiter, and Saturn are considered. We have partially tested the models of Uranus by comparing the dependence of their disk integrated brightness on phase angle with that derived from a combination of ground-based and Voyager 1 data that span phase angles from 0° to 85° and by comparing the predicted shapes of several H_2 quadrupole lines with observed shapes. Predictions of the Neptune models were compared with determinations of the planet's disk integrated brightness from 0° to 48° phase angle.

The derived model parameters lie within useful bounds. In the case of Uranus, the cloud pressure for all 7 models considered falls between 2.2 and 2.5 bars, implying methane mixing ratios in the deeper portion of the atmosphere that are at least 30 times higher than expected from solar elemental abundances if the cloud is interpreted as being a methane condensation cloud. The range of haze pressure (< 0.5 bars) and optical depths (0.06 to 0.6 at a wavelength of 0.6435 μm) imply that haze aerosols are a significant absorber of sunlight and hence constitute a significant heating source in Uranus' upper troposphere and stratosphere. The haze aerosols absorb strongly at both short and long visible wavelengths, unlike the aerosols in Titan's atmosphere.

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Qualitatively similar conclusions apply to our model atmosphere of Neptune, with the cloud pressure being somewhat higher than for Uranus (2.7-3.2 bars) and the methane abundance being at least 60 times higher than expected from solar elemental abundances.

At the current epoch, the wavelength averaged phase integrals of Uranus and Neptune equal 1.26 ± 0.11 and 1.25 ± 0.1, respectively. The corresponding bolometric albedos are 0.343 ± 0.055 and 0.282 ± 0.044 respectively. When averaged over an orbital period, these albedos may be 7 percent lower for Uranus and little altered for Neptune, based on measurements of their secular brightness variability. Comparison of these results with thermal observations implies that the internal heat source for Uranus is less than 0.27 times the solar input (specific luminosity $< 1.6 \times 10^{-7}$ *erg* $s^{-1}g^{-1}$*), while this value for Neptune is (1.85 ± 0.56) times its solar input (specific luminosity =* $3.4 \pm 1.1) \times 10^{-7}$ *erg* $s^{-1}g^{-1}$*). These results imply that the meteorological regimes in the observable atmospheres of Uranus and Neptune may be very different, with internal heat flux playing a much more important role for Neptune than for Uranus.*

DR. APPLEBY: I don't understand how you can come up with tight constraints on the phase integral for the following reason. Marty Tomasko did some test calculations to help me with the aerosol heating problem, and everything he did indicated that uncertainties in the phase function of the cloud material in the troposphere, not to mention variations in the phase function of the haze particles higher up in the atmosphere, influence the phase integral by as much as 25 percent at 7000-8000 angstroms. What constrains the phase integral to the much smaller range indicated in your figure?

DR. POLLACK: Our basic strategy here was to pick a wide range of feasible single scattering phase functions to range all the way from isotropic to highly anisotropic ones that are typical for Titan, Saturn, and Jupiter. Surprisingly, we did indeed find out that the phase integral has turned out to be reasonably constrained. I think there are several reasons for that. Number one, there is a very large contribution from molecular Rayleigh scattering, and that tends to make the overall effect more isotropic in character than you would tend to think. Secondly, the differences between the different single scattering phase functions actually become important only at the largest and smallest phase angles. So what that means is that when you're computing the phase integral, much of the contribution comes from the range of phase angles where you would expect it to be relatively insensitive. For the whole range of models calculated, our differences were approximately ± 10 percent.

DR. LUTZ: I just want to emphasize something you said to make sure that people remember it. When you bootstrap your way with the absorption coefficients using liquid methane in the centers (and that's what we've got to do), it's really a little risky; so it's important to remember that we've got to do the absorption coefficients right at low temperatures. I think that Bill Smith's cell data shows us interestingly enough that the band centers could shift and everything. If we don't do it right in the lab, we may be in bad shape.

DR. POLLACK: First of all, I couldn't agree with you more. I really think that the sort of measurements that Bill has been doing is tremendously important, and I must say that I'm very dismayed to hear that he may have a problem in continuing to do this work in the future because of questions about support. I think it's very vital that such work get done. To explain some of the logic behind our approach, let me point out that Larry Giver was kind enough to make some comparisons between his room temperature gas measurements and liquid methane absorption coefficients. It is really incredible, but for almost every band that one makes a comparison, the absorption coefficients are very similar in the band center. So our philosophy was to avoid the wings of bands where you do in fact expect the temperature effects to be the largest and to focus on the band centers where you expect them to be small.

DR. MCKINNON: I take it that the internal heat flux limit you gave of 0.27 times solar does not include the phenomena that the previous speaker, Dr. Bezard, mentioned, where the long-term average and what one measures could be different by several degrees.

DR. POLLACK: Yes, in fact I think that is really one level of sophistication that is going to be needed. Once one has the Voyager data, I think one wants to think very hard about some seasonal effects in terms of the secular variations of brightness to really pin things down. I think Voyager will be very helpful in the sense that it will be the first time that we are able to observe both bright and dark sides.

DR. ORTON: I find it personally very interesting that both you and Kevin Baines independently came up with a methane mixing ratio that evolved into these calculations. To some extent they are independent results. I might ask one question as sort of a follow-up to the results which you described. Is there any constraint given by the level of sophistication of the models that displaces current Voyager observations of Uranus?

DR. POLLACK: I'd like to say two things. First, because I had a limited time, I didn't adequately acknowledge the very important contributions that Kevin has made in this area. Many of the qualitative conclusions we came to in terms of cloud pressure bounds and in terms of absorption in the near infrared, were really first made by Kevin's modeling, and we should acknowledge him for that. In terms of bounds by Voyager at present, our original thought was that now that we have some phase angle data, we can really start eliminating some of the models. In fact, when you're at intermediate phase angles, that's the time when you have the least discriminability among models. So in retrospect, it would have been nice if Voyager data had covered more diagnostic phase angle ranges. That's water under the bridge, and I think the good point is that the encounter will really give us phase angles in the ranges where we do have discriminability.